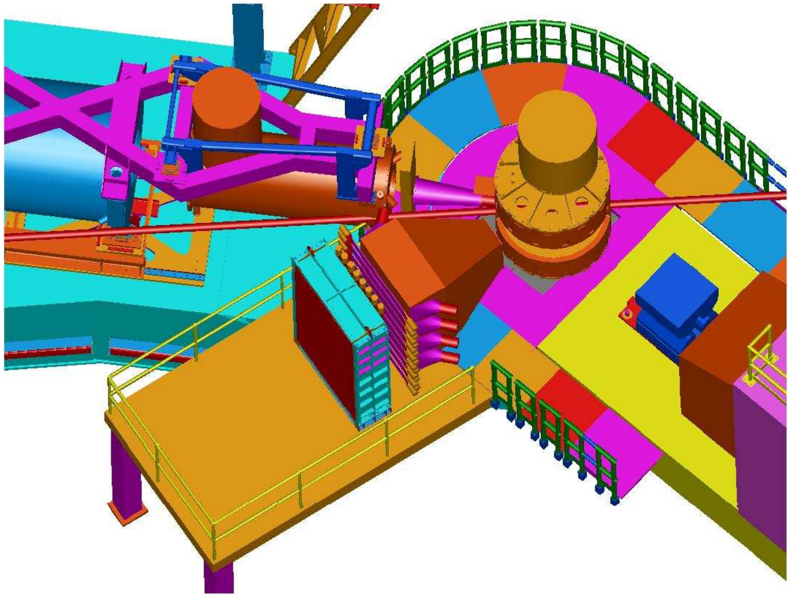
Semi-SANE: A Jefferson Lab Hall C Experiment

E04-113: P. Bosted, D. Day, X. Jiang and M. Jones co-spokespersons

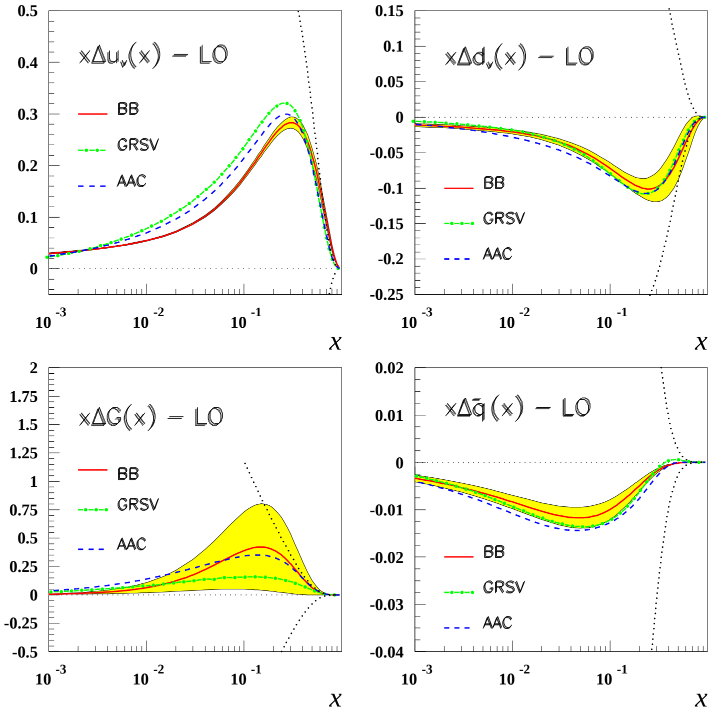
ANL, Duke, FIU, Hampton, JLab, Kentucky, UMass, Norfolk, ODU, RPI, Rutgers, Temple, UVa, W&M, Yerevan, Regina, IHEP-Protvino.

High precision asymmetry data in deep-inelastic $\vec{N}(\vec{e}, e'h)$ ($N = p, d$, $h = \pi^{\pm}, K^{\pm}$).



- $E_0 = 6$ GeV, $P_B = 0.80$.
- e-Arm: a calorimeter array $@30^{\circ}$.
- h-Arm: HMS spectrometer @10.8°, 2.71 GeV/c, $z \approx 0.5$. Particle ID detectors for π/K separation.
- Target: polarized NH_3 ($\vec{p}$) and LiD ($\vec{d} = \vec{p} + \vec{n}$).

Nucleon Spin Structure — in Flavor

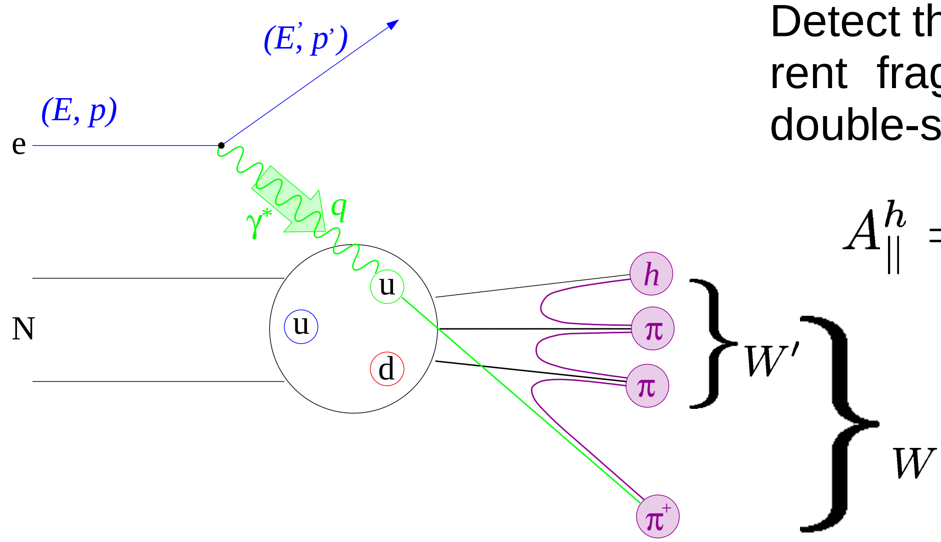


Global QCD fits to the inclusive DIS data.

- Have to assume the sea behavior. As in BB: $\Delta\bar{q} = \Delta\bar{u} = \Delta\bar{d} = \Delta\bar{s}$.
- Inclusive data can not distinguish between q and $\bar{q}$ since $\sigma = \sum_f e_f^2 q_f$.
- Only one flavor non-singlet accessible: $\Delta q_3 = (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d})$.
- Can not access $\Delta\bar{u} - \Delta\bar{d}$.

Semi-inclusive deep inelastic scattering (SIDIS) offers extra handle of q vs $\bar{q}$ due to flavor tagging. Provide access to the valence and the sea structure of the nucleon spin.

Flavor Tagging in Semi-Inclusive DIS



Detect the leading hadron from the current fragmentation and measure the double-spin asymmetry:

$$A_{\parallel}^{h} = f^{h} P_B P_T \cdot \mathcal{P}_{kin} \cdot A_{1N}^{h}$$

$$z = E_{\pi}/\nu$$

Assume the leading order naive x-z factorization (name invented by Ji, Ma and Yuan):

$$A_{1N}^{h}(x, Q^2, z) \equiv \frac{\Delta\sigma^h(x, Q^2, z)}{\sigma^h(x, Q^2, z)} = \frac{\sum_f e_f^2 \Delta q_f(x, Q^2) \cdot D_f^h(z, Q^2)}{\sum_f e_f^2 q_f(x, Q^2) \cdot D_f^h(z, Q^2)}.$$

Each asymmetry measurement provides an independent constrain on Δq_f.

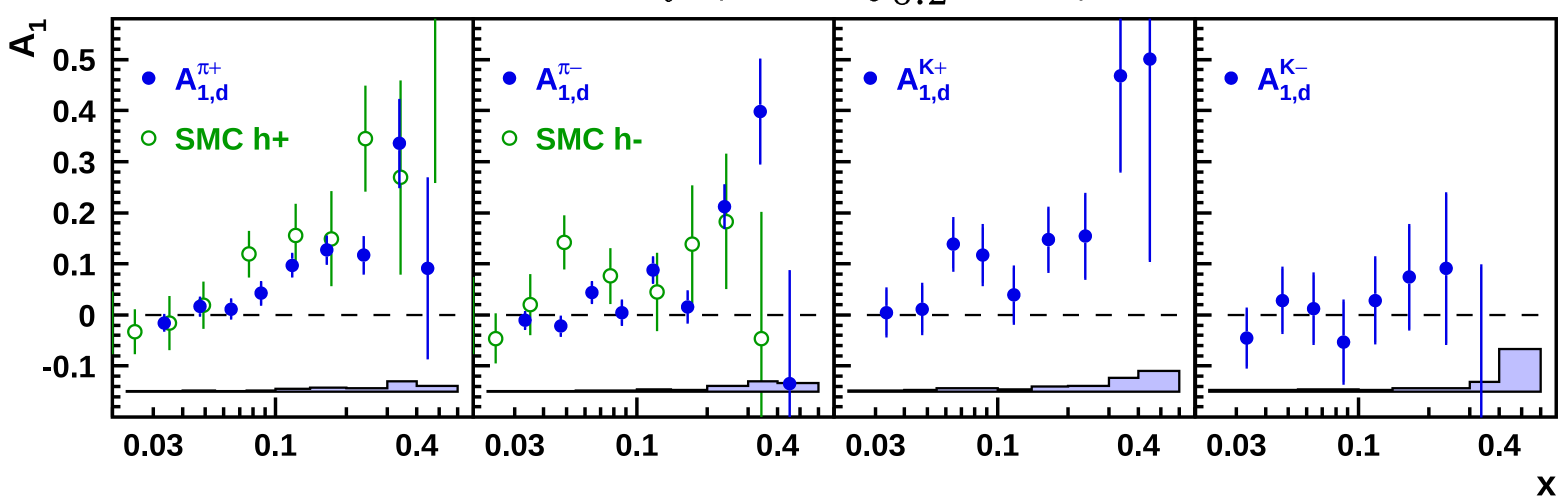
HERMES Flavor Decomposition: $\vec{A} = \mathcal{P}_f^h(x) \cdot \vec{Q}$

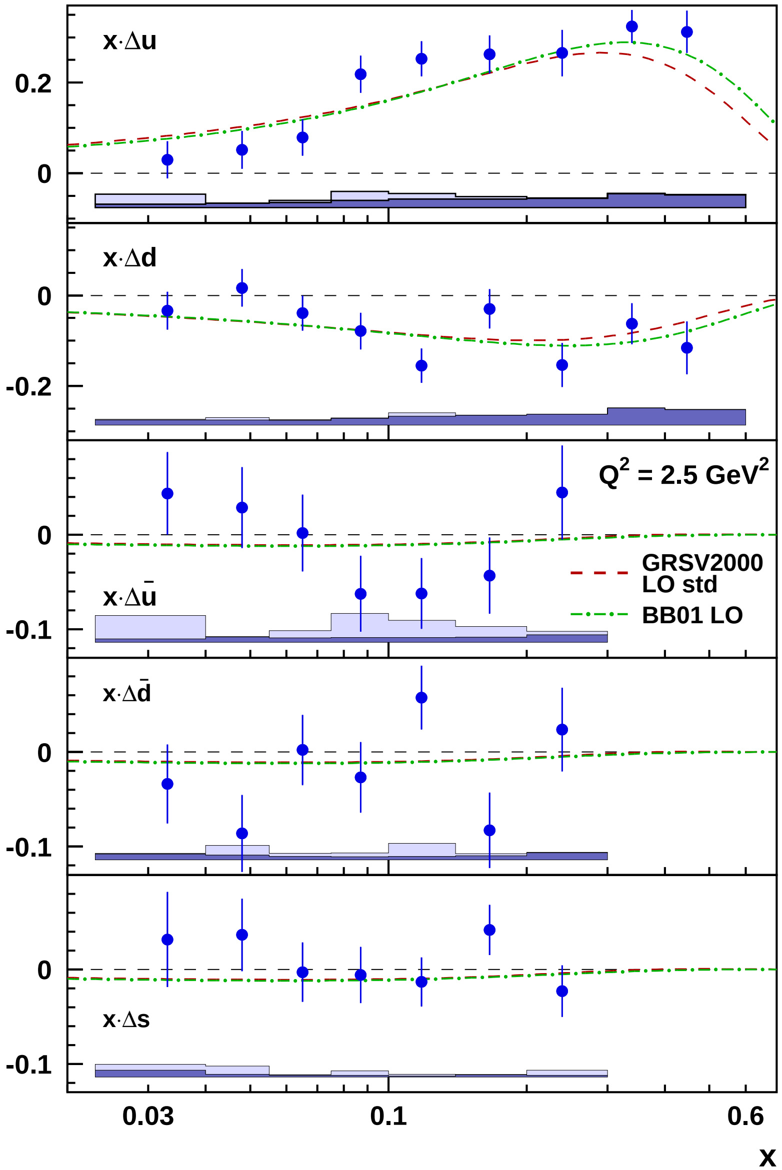
From measurements: $\vec{A} = \left(A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, A_{1d}^{\pi^+}, A_{1d}^{\pi^-}, A_{1d}^{K^+}, A_{1d}^{K^-}, A_{1p}, A_{1d}\right)$

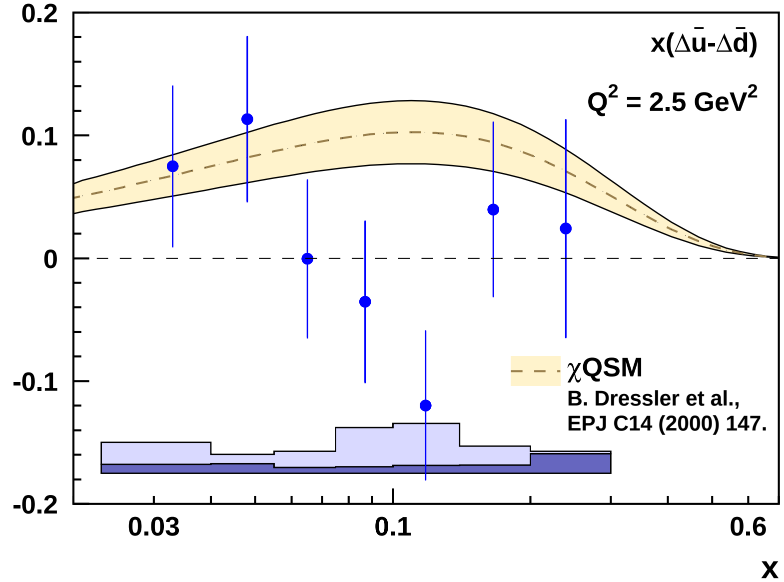
Solve for: $\vec{Q} = \left(x\Delta u, x\Delta d, x\Delta\bar{u}, x\Delta\bar{d}, x\Delta s\right)$.

Calculate “Purity” from a LUND based Monte Carlo:

$$\mathcal{P}_f^h(x) = \frac{e_f^2 q_f(x) \int_{0.2}^{0.8} dz D_f^h(z)}{\sum_i e_i^2 q_i(x) \int_{0.2}^{0.8} dz D_i^h(z)}$$







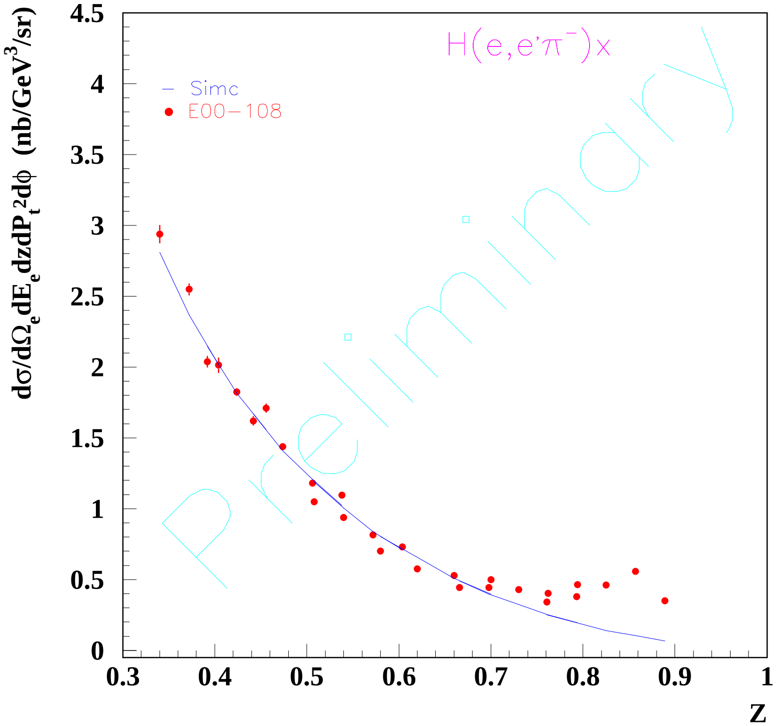
Assumes:

Leading order x-z factorization and current fragmentation.

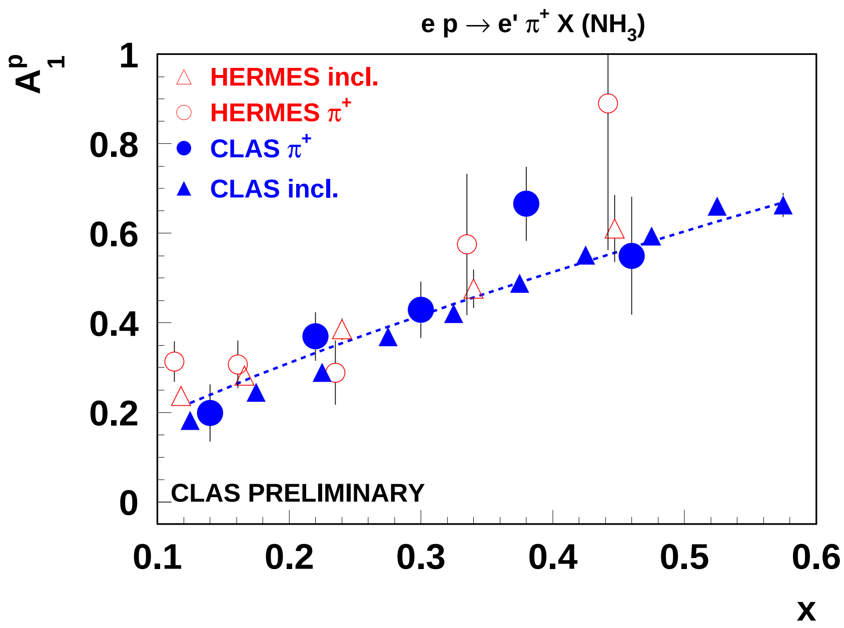
Isospin symmetry and charge conjugation.

Purity from Monte Carlo.

Leading-Order Naive x-z Factorization at JLab 6 GeV ?



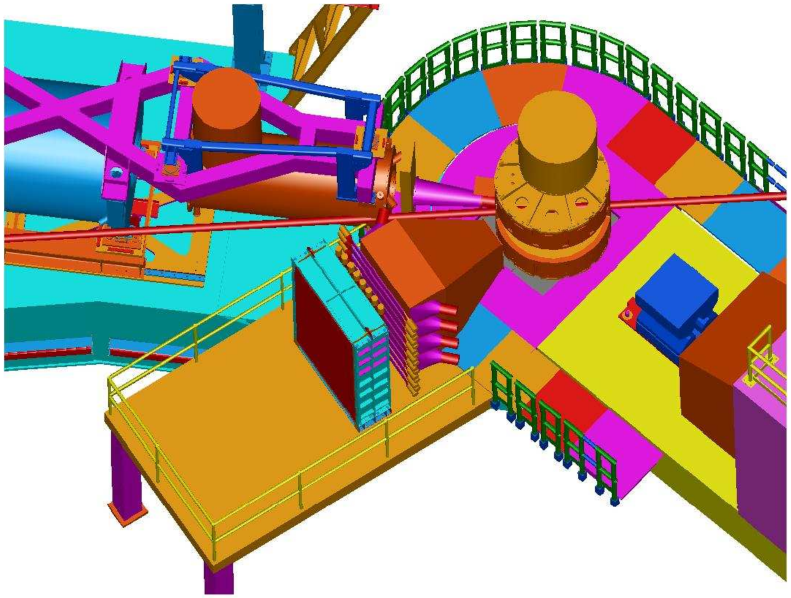
Hall C E00-108 preliminary. Cross section reproduced by a Monte Carlo based on LO x-z factorization.



Hall B eg1b: semi-inclusive asymmetry $A_{1p}^{\pi^+}$ agree with HERMES, SMC, fall on the same curve of inclusive A_{1p}. No clear z-dependence observed for $z > 0.5$.

Leading order naive x-z factorization is not violated much.

The Semi-SANE Experiment: $\vec{N}(\vec{e}, e'h)$



- $E_0 = 6$ GeV, I=80 nA $P_B = 0.80$.
- e-Arm: BETA as in SANE, $\Delta\Omega \approx 200$ msr, $@30^\circ$ in stead of 40°. GEP-III calorimeter + gas Č.
- h-Arm: HMS@10.8°, 2.71 GeV/c, $z \approx 0.5$. Gas Č + aerogel for π/K identification
- Target: long. polarized NH_3 and LiD (SLAC and Hall C).

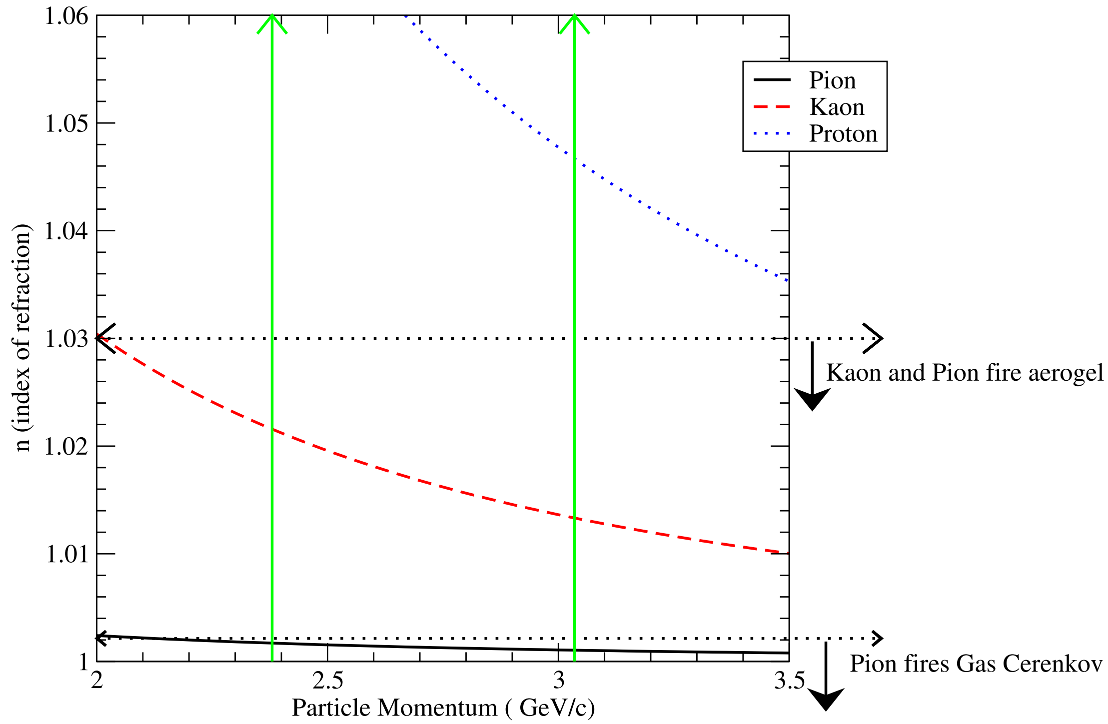
Well-controlled phase space and hadron PID

$$A_{1N}^{\pi^+\pm\pi^-} = \frac{\Delta\sigma_N^{\pi^+} \pm \Delta\sigma_N^{\pi^-}}{\sigma_N^{\pi^+} \pm \sigma_N^{\pi^-}} = \frac{A_{1N}^{\pi^+} \pm A_{1N}^{\pi^-} \cdot r}{1 \pm r}, \quad r = \frac{\sigma^{\pi^-}}{\sigma^{\pi^+}} = 0.27 \sim 0.64.$$

(Method not applies for low-z experiments where $\sigma^{\pi^-}/\sigma^{\pi^+} \sim 1.0$)

Fit into the SANE (E03-109) setup, need a few shifts of change-over time.

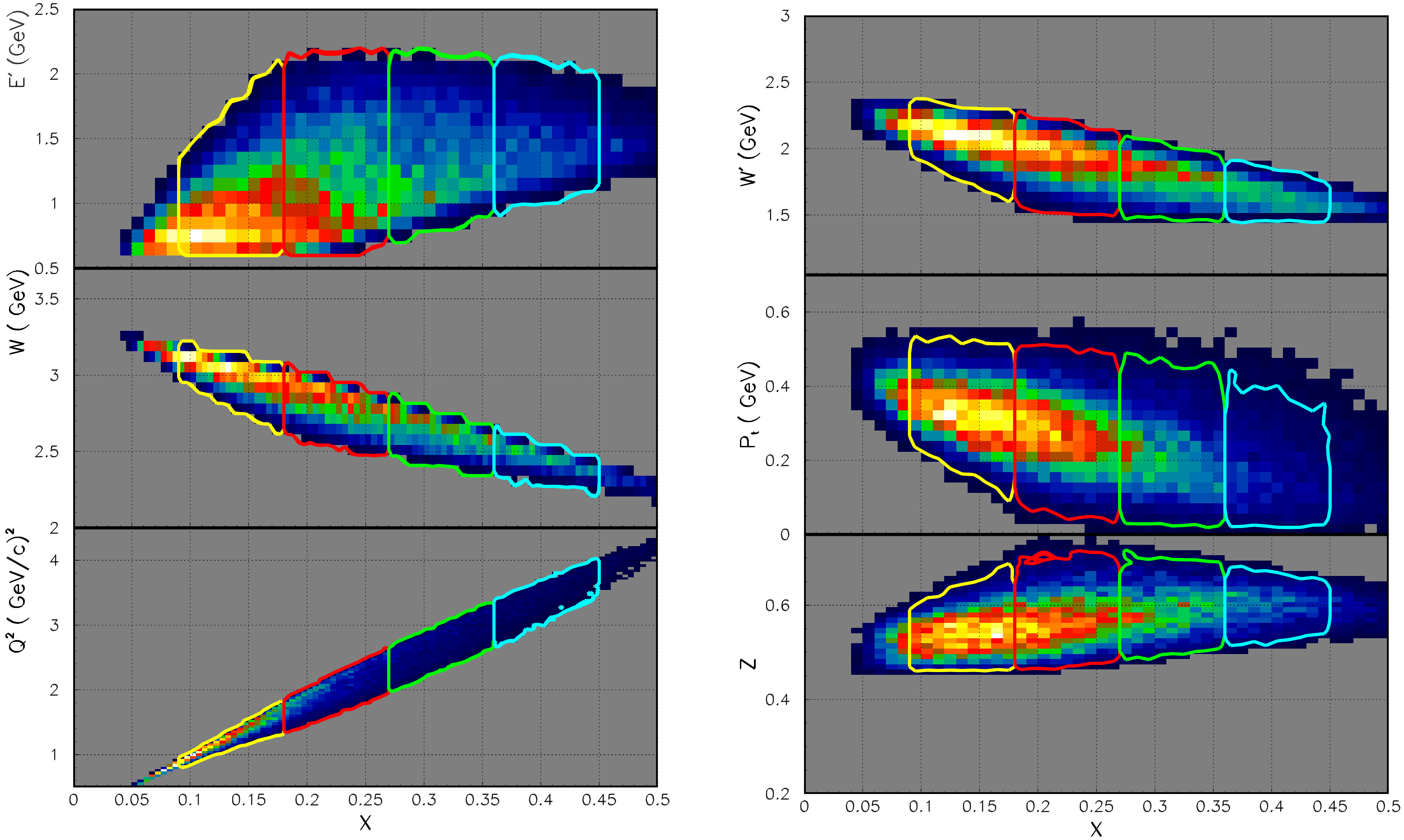
Particle Identification in HMS



A pure pion sample for flavor decomposition. Free Kaons for extra physics.

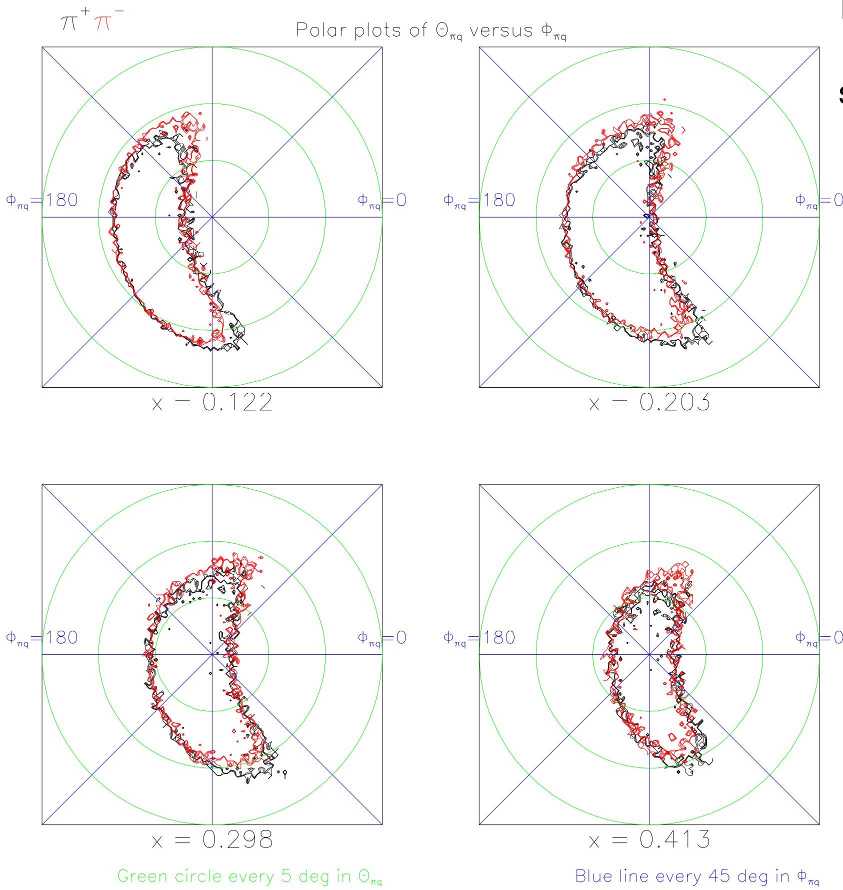
- Existing gas Č (@1.5atm) and aerogel detector ($n = 1.030$) provide π/K separation.
- Shower counters provide clear π^-/e^- separation.
- $P_{HMS} = 2.71$ GeV/c, focus on $z \approx 0.5$ events.
- HMS-BETA time-of-flight helps to eliminate accidentals.

Kinematics and Phase Space Coverage



$0.122 < x < 0.413$, $\langle Q^2 \rangle = 2.2$ GeV^2. $z > 0.5$. Only shown $W' > 1.5$ GeV.

Angular Coverage in (θ_{qh}, ϕ_l^h)



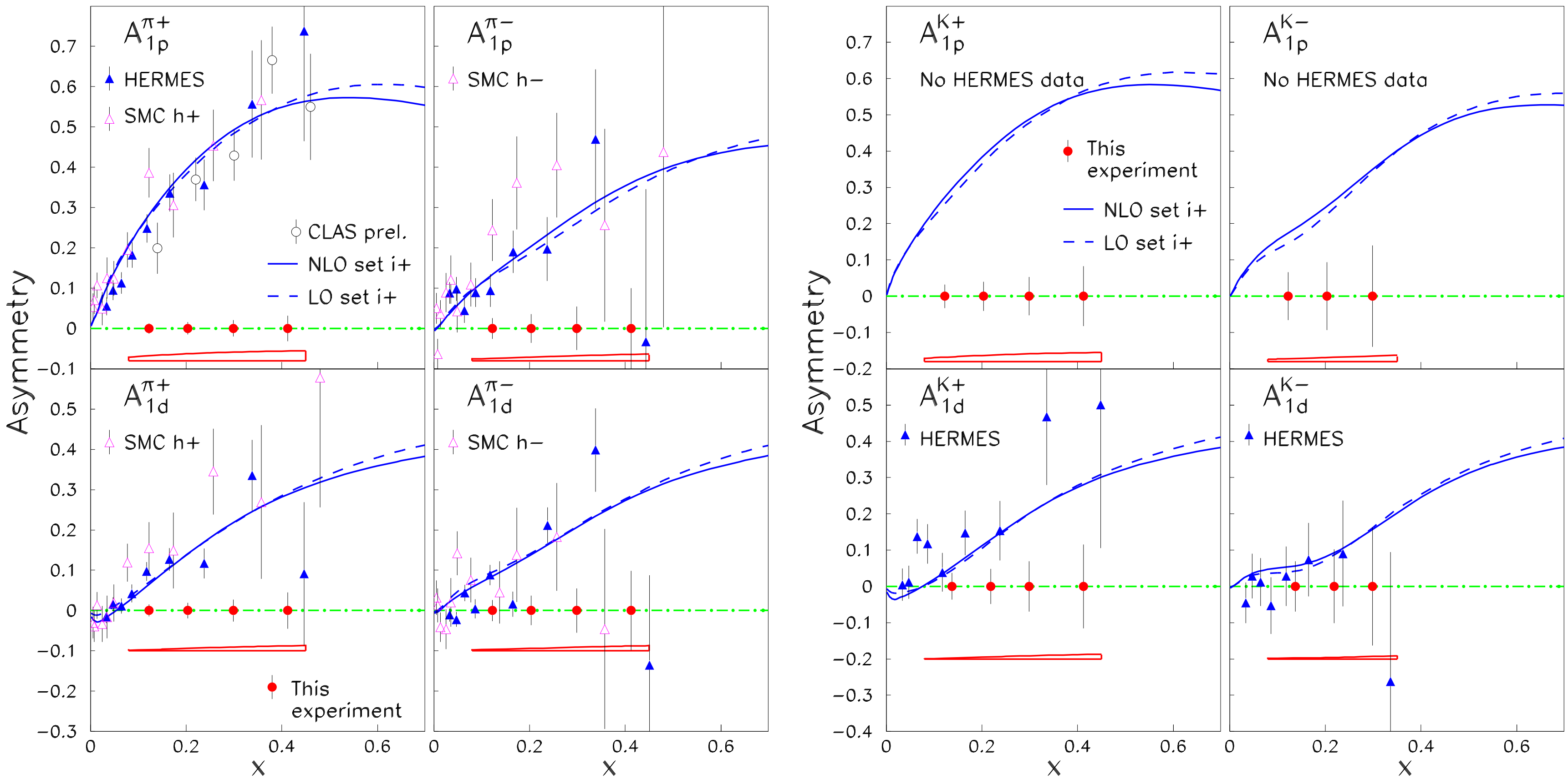
We cover at least 180° in ϕ_l^h.

Related terms in ϕ_l^h:

see Boer and Mulders, PRD57, 5780 (1998)

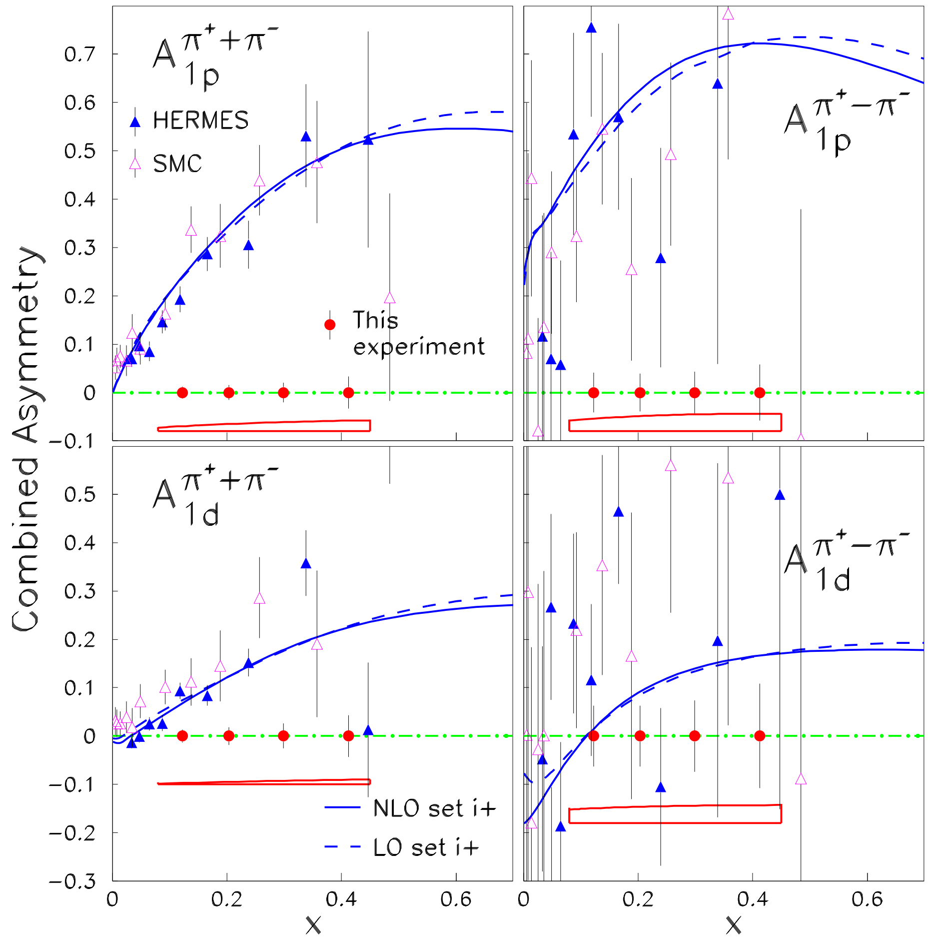
- $\cos(2\phi_l^h)$ term in $d\sigma^h$ averaged out.
- $\cos(\phi_l^h)$ term in A_{LL} is small ($\propto S_T$), reverse sign when target spin is reversed.
- Unexpected $\sin(\phi_l^h)$ term in A_{LL} can be checked with data.
- Extra free physics: large enough coverage in ϕ_l^h even allow extraction of single-spin asymmetry A_{UL} for $\sin\phi_l^h$ and $\sin(2\phi_l^h)$ moments.

The Expected Results: Double-Spin Asymmetries A_{1N}^{h}



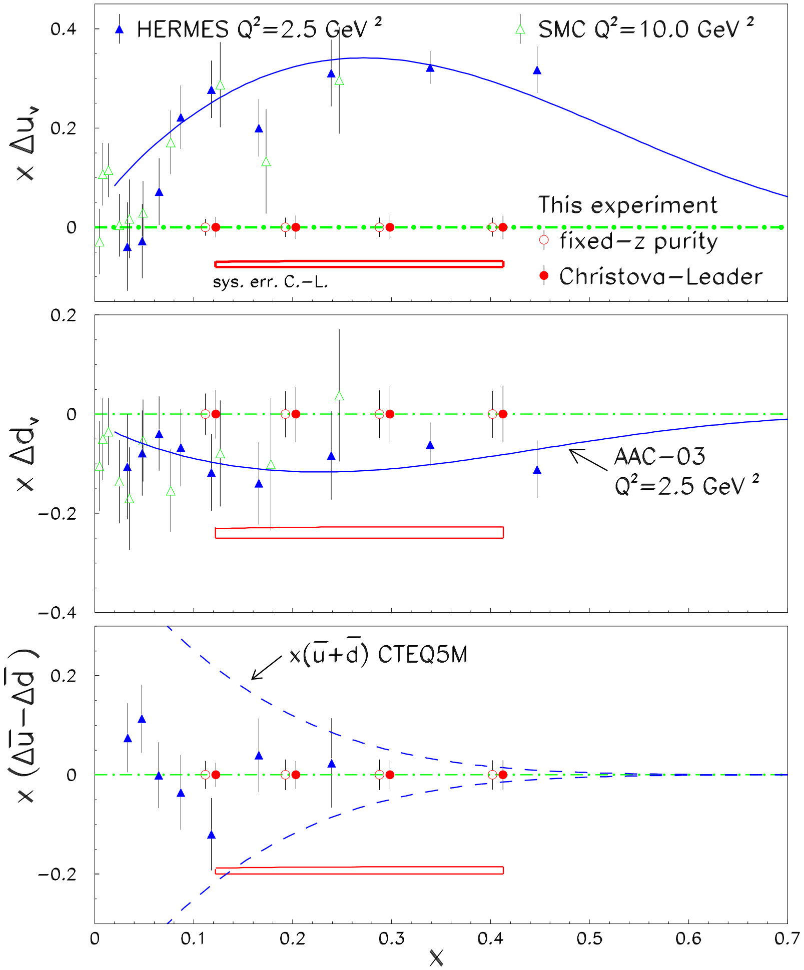
Approved for 25 days beam time. Significant improvements on the statistical accuracy of $A_{1N}^{\pi^{\pm}}$.
First data on $A_{1p}^{K^{\pm}}$.

The Combined Asymmetries: $A_{1N}^{\pi^+ + \pi^-}$ and $A_{1N}^{\pi^+ - \pi^-}$



Get rid of some higher order complications by using the observables related to $\pi^+ - \pi^-$.

The Expected Results on Δq



Jefferson Lab E04-113
$E_0 = 6$ GeV

$$\Delta u_v = \Delta u - \Delta \bar{u}$$
$$\Delta d_v = \Delta d - \Delta \bar{d}$$

Tow independent methods of flavor decomposition:

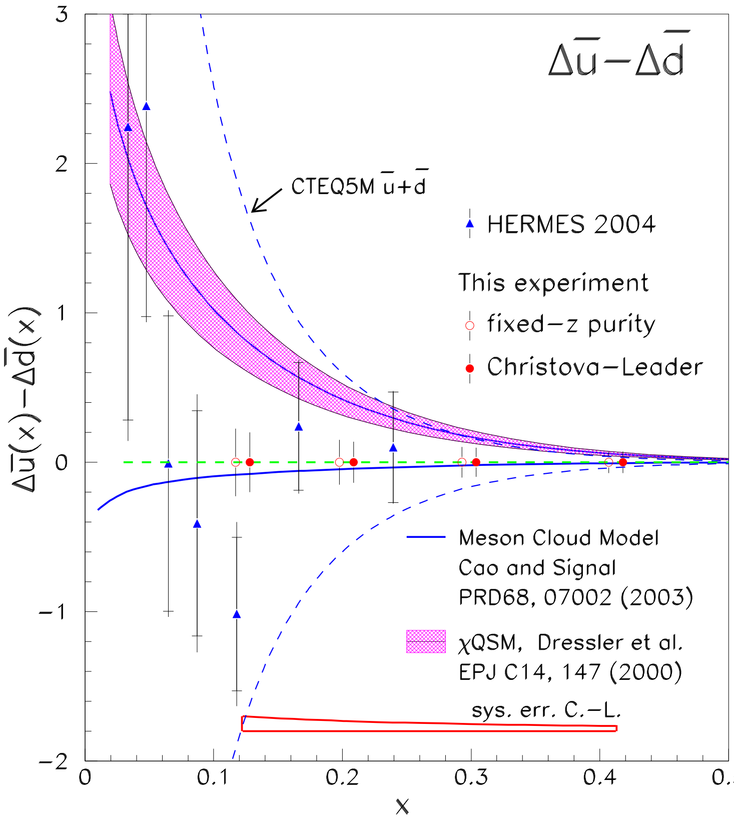
i, Christova-Leader method.

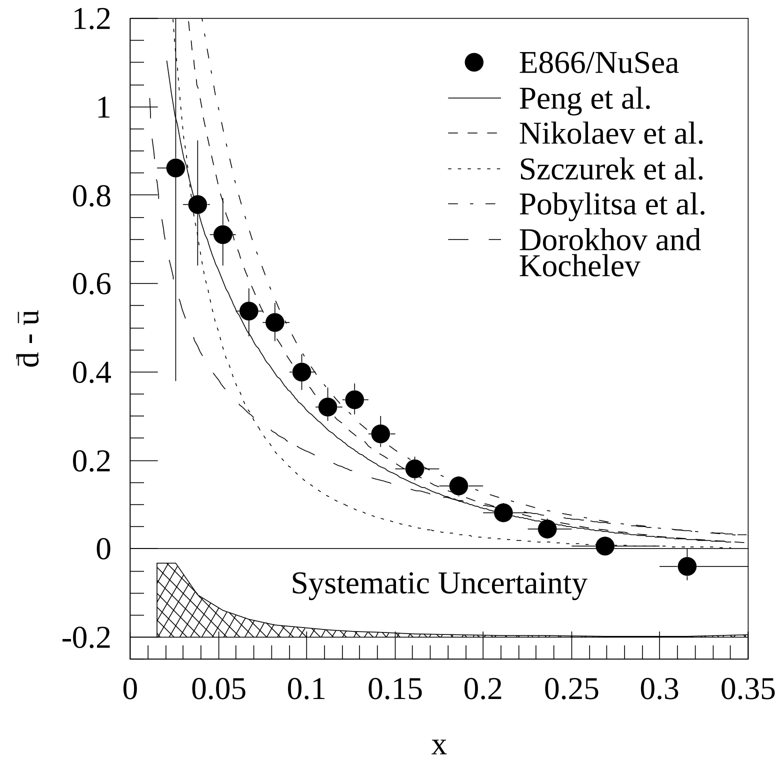
ii, “Purity” at a fixed-z.

Statistical uncertainties dominate.

One expects at least $\Delta \bar{u} - \Delta \bar{d} > (\bar{d} - \bar{u})$!!!

Flavor Asymmetry in the Nucleon Sea





Many other model predicted large $\Delta\bar{u} - \Delta\bar{d}$. In Chiral-quark soliton model, $\Delta\bar{u} - \Delta\bar{d}$ appears in LO (N_c^2) while $\bar{d} - \bar{u}$ appears in NLO (N_c).

Fermilab $pp, pd \to \mu^+\mu^-$ data. Many models explain $\bar{d} - \bar{u}$, including the meson-cloud model (π) which predicts $\Delta\bar{u} = \Delta\bar{d} = 0$.

Pauli-blocking model: $\int_0^1 [\Delta\bar{u}(x) - \Delta\bar{d}(x)]dx = \frac{5}{3} \cdot \int_0^1 [\bar{d}(x) - \bar{u}(x)]dx \approx 0.2$.

Test a wide range of model predictions of $\int_0^1 (\Delta\bar{u} - \Delta\bar{d})dx$:

- Meson cloud (π) model: 0.
- Chiral-quark soliton model: 0.31.
- Pauli-blocking model: $0.2 \sim 0.3$.
- Instanton model: 0.2
- Statistical model: 0.12

Methods of Spin-Flavor Decomposition

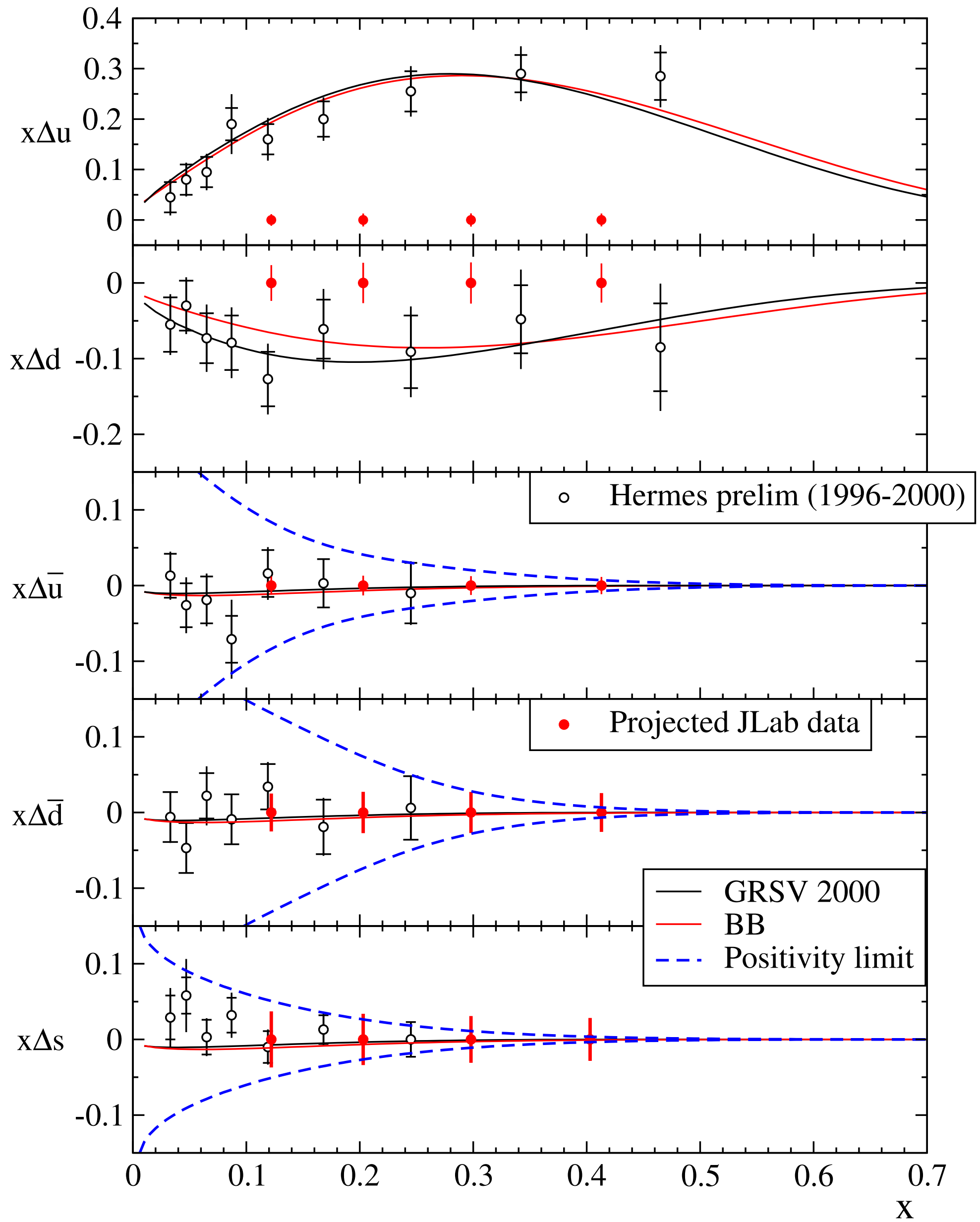
Four leading-order methods:

- The LO Christova-Leader method: $A_{1p}^{\pi^+-\pi^-}$, $A_{1d}^{\pi^+-\pi^-} \Rightarrow \Delta u_v, \Delta d_v$. Use $g_1^p(x) - g_1^n(x)$ as inputs to obtain $\Delta\bar{u} - \Delta\bar{d}$.
- "Fixed-z purity" method: calculate purity (inputs: PDFs and ratio of $D^-(z)/D^+(z)$) for well-localized z-bins. Solve linear equations $\vec{A}(x,z) = \mathcal{P}(x,z)\vec{Q}(x)$.
- Monte Carlo purity method (HERMES). Purity from a LUND based Monte Carlo.
- LO global fit.

Two next-to-leading order methods:

- The NLO Christova-Leader method (inputs: PDFs and $D^+(z) - D^-(z)$).
- NLO global fit method (D. de Florian, G. Navarro and R. Sassot hep-ex/0504155).

Consistency checks between different methods provide clear measures of systematic uncertainty associated with the flavor decomposition methods.



Five-Flavor Δq: the Fixed-z Method

Systematic uncertainties are expected to be similar to that of HERMES.

Except that:

- Only the ratios of fragmentation functions are involved in the purity at fixed-z.

High precision asymmetry data in deep-inelastic $\vec{N}(\vec{e}, e'h)$ ($N = p, d$, $h = \pi^{\pm}, K^{\pm}$).

- Double-spin asymmetry A_{1N}^{h} and the combined asymmetry $A_{1N}^{h\pm\bar{h}}$.
- Δu_v, Δd_v from $A_{1N}^{\pi^+-\pi^-}$ at LO and NLO (Christova-Leader method).
  Sensitive to $\Delta\bar{u} - \Delta\bar{d}$ when combined with inclusive data $g_1^p - g_1^n$.

Built-in measures of systematic uncertainties:

- Measure the violation of LO x-z factorization using $A_{1N}^{\pi^++\pi^-} - A_{1N}$.
- Four independent methods of LO spin-flavor decomposition, two NLO methods.

Fit into the SANE setup (E03-109). Request 25 days of 6 GeV beam in Hall C.